Boundary Stress Over Rough Topography

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LONG-TERM GOAL

Our long-term goal is to understand the how bottom topography affects oceanic circulation and mixing. This is particularly important in coastal regions, where current interactions with rough slopes can force turbulent mixing and strong eddy and wave activity.

OBJECTIVES

In this project I focus on the question: What scales of bottom roughness are most effective for the creation of bottom form stress? By bottom roughness I mean chiefly the little-explored scale range of bumps, hills, and ridges which are too large to be hidden within the turbulent bottom boundary layer, and yet which are smaller than about 2 km, so the overlying horizontal flow may have difficulty following isobaths. The most compelling region to explore is the sloping edges of the ocean: continental slopes and shelves. There one may generate internal waves and internal tides, and the intersection of density surfaces with the slope can also give rise to horizontal vorticity-carrying eddies which are not wave-like, an effective but little-understood means to transmit momentum to the topography.

While this study is aiming mainly at momentum issues, clearly it is related to turbulent mixing generated at the boundary, and I interact with several researchers who are looking at this.

APPROACH

In conjunction with my studies funded by the SECNAV/CNO Award (N00014-97-1-1053) with Dr. Mike Gregg, I am using several approaches to answer and refine the question of form stress on rough slopes. I am using idealized numerical simulations of stratified, rotating flow along a slope with a single headland ridge to explore the response of the flow. Two scales define the parameter space. The first is the speed of the along-slope flow compared to the maximum phase speed of internal waves generated by the topography. Near this speed the flow will tend to go over the bumps, and internal wave generation can cause substantial form stress. Much slower than this speed the flow will tend to flow around the bathymetry, and this is where the other parameter, the horizontal curvature of isobaths, becomes important, because a very abrupt curve can cause horizontal flow separation.

With the assistance of a postdoc, Geno Pawlak, I am preparing laboratory experiments which will be similar in configuration to the numerical work. The lab experiments one can achieve greater resolution, particularly for horizontal eddies. With my graduate student Tiangang Yu, we are making oceanic observations near one of the steep, rough slopes bounding the Strait of Juan de Fuca.

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WORK COMPLETED

Numerical: we have begun using the newest version of the Hallberg Isopycnic Model, which supports a Richardson Number dependent mixing parameterization. Also more disk space was purchased for the workstation. Preliminary simulations have been done.

Analytical: we are looking at analytical solutions to the problem of non-rotating internal waves generated by flow past a sloping, corrugated boundary. This provides the fundamental framework for the generation of form stress by wave generation, and gives the parameter space to place other work in a dynamical context.

Laboratory: we have constructed a 2.5 m Plexiglas tank with sloping sidewalls, a tide maker, Particle Imaging Velocimetry (PIV) system, and micro CTD.

Observational: we purchased an ADCP and successfully deployed it for one month in a bottom mooring near the steep southern wall of the Strait of Juan de Fuca. This was done in conjunction with the Canadian group led by Chris Garrett. A mooring to measure stratification throughout the water column was also deployed next to the ADCP. The data are being analyzed by the graduate student, Tiangang Yu.

RESULTS

The numerical simulations demonstrate that isopycnal eddies may be readily generated by flow past a sloping ridge (Fig. 1). The eddies appear to be generated when the horizontal scale of the headland normal to the slope is similar to its scale along the slope (or bigger). The vorticity generation mechanism is the relatively large horizontal projection of the bottom boundary layer due to the fact that isopycnals intersect the slope at a shallow angle.

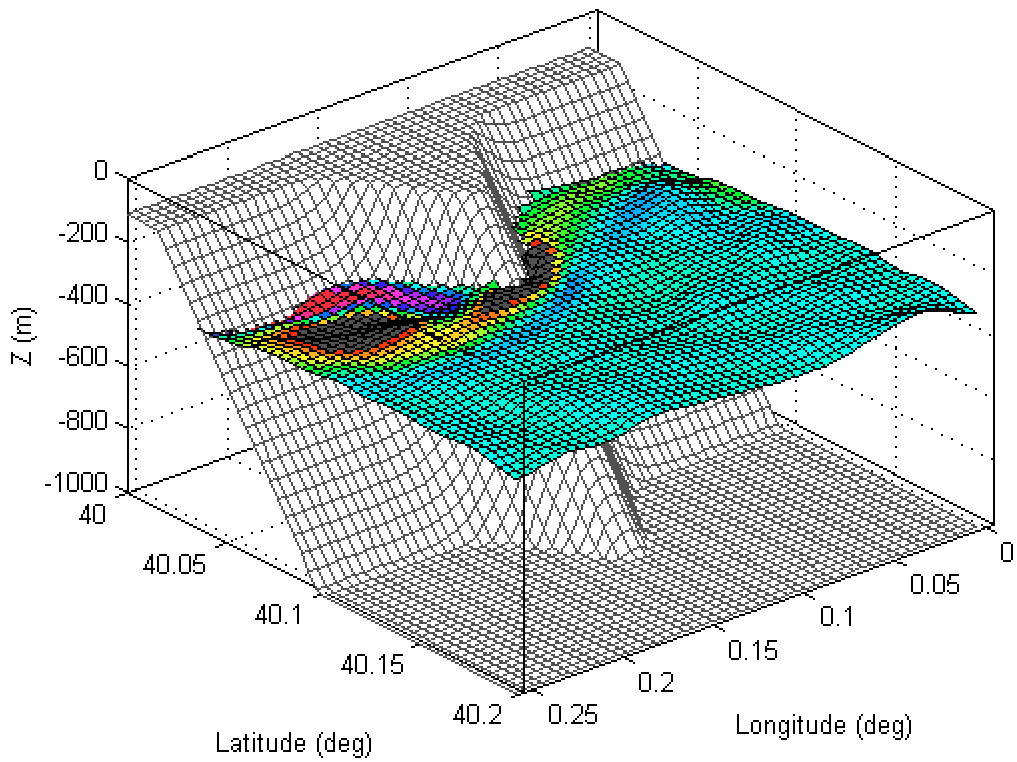

Figure 1. Results from a numerical simulation of rotating, stratified flow past a ridge on a slope. The relative vorticity within the fourth of ten vertical layers is shown by the color, with some exaggeration of the vertical undulations. The flow in this reentrant channel is initially heading to the left, and boundary friction causes the large negative relative vorticity (2 to 3 times as big a Coriolis) which is then swept into the interior as an isopycnal eddy. The effect is to enhance the frictional coupling of the flow with the boundary.

Early analysis of the observations from Juan de Fuca indicates substantial mean offshore flow at some depths, despite the fact that the dominant tidal flow is strongly oriented along the coast. We may be observing a localized effect of tidal eddy generation by two nearby headlands (each about a half of a tidal excursion up and down channel). Such eddy generation could readily generate a mean secondary horizontal circulation, due to the self-advection of opposite-signed eddies generated on opposite tides.

IMPACT/APPLICATION

The range of scales considered here has received little study in the past, often being larger than the turbulent bottom boundary layer but smaller than the horizontal grid used for numerical modeling. Particularly on coastal slopes where tidal currents are strong the eddies and waves generated by such topographic roughness has the possibility to greatly increase the boundary stress experienced by the overlying flow. In addition such eddies are the way in which the interior horizontal mixing due to mesoscale eddied 'attaches' to the boundary. This is the likely means by which fluid mixed in the turbulent boundary layer is exchanged with unmixed interior fluid. The rate of this exchange is a big unknown in Physical Oceanography, and may determine whether boundary mixing is a globally important phenomenon or not.

TRANSITIONS

We are sharing Juan de Fuca data with Chris Garrett's group at University of Victoria. His continuing field program provides an essential context of larger scale physical measurements in which to place our work on boundary processes.

RELATED PROJECTS

1 – LuAnne Thompson (UW) is doing laboratory and numerical experiments on flow past irregular slopes, but at larger scale where rotational effects are important. Her results should provide a useful endpoint to ours.

2 – Eric Kunze (UW) has made measurements near Monterey Canyon which can reveal vorticity-carrying horizontal eddies. We hope to compare his observations with numerical simulations done at a similar scale.

3 – Mike Gregg (UW/APL) is analyzing coastal turbulent mixing. We work together through the SECNAV/CNO Chair-Scholar Award.

4 – Chris Garrett (U. Vic.) leads the effort to make observations in the Strait of Juan de Fuca.